Analysis of Potential Leakage Pathways and Mineralization within Caprocks for Geologic Storage of CO_2

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage

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Presentation Outline

- Benefits
- Goals and Objectives
- Relationship to overall program goals
- Overview of seal bypass
- Technical status; bypass systems
  - Field based studies
  - Technological advances
- Accomplishments and Summary
- Appendices

Benefit to the Program

- Program goals addressed
- Develop technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.

- Project Benefits

Geologic storage of CO_2 requires that effective seals exists for the lifetime of the project, and beyond. We examine the nature of the top of reservoir analogs, and their overlying seals, in naturally occurring analogs, and are developing methods to quantify the mechanical properties of the overlying caprock.

Project Overview:
Goals and Objectives

Objectives:

- We examine the integrity of cap rocks, and mechanisms of seal bypass, in exhumed analogs of CO_2 flow systems in order to determine the processes by which CO2 may flow through top sealing rocks.
- We focus on the presence of fractures or faults in cap rocks, as they are one of the key features that may lead to seal failure.
- Use data to condition mechanical models of the response of cap rocks to fracture propagation, and maximum fluid pressures
- Use research projects to educate and train students in the science and technology of carbon capture and storage

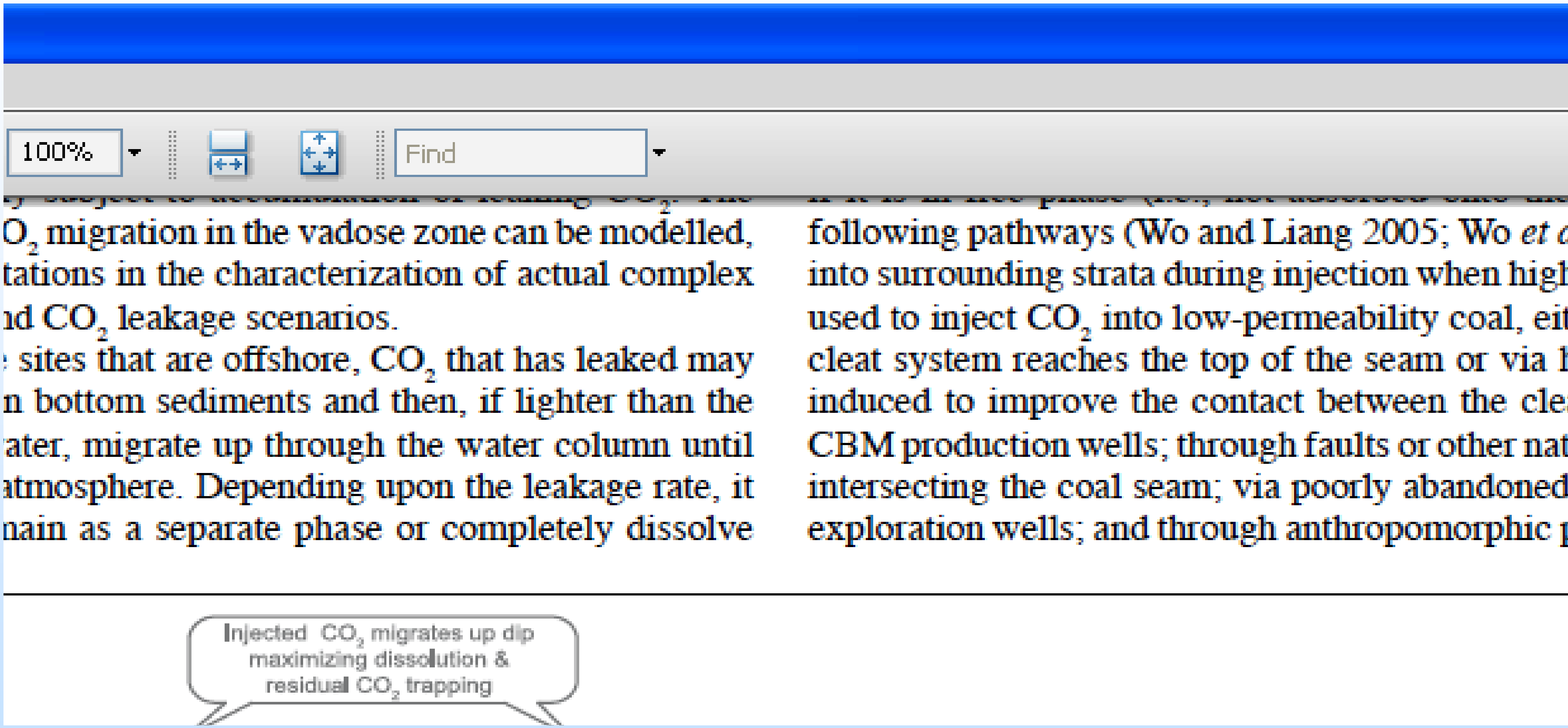
Project Goals

- Evaluate geologic controls on the microscopic and mesoscopic fracture patterns/networks in mudstones from field and drill core samples to examine the deformation and sedimentology of the caprocks
- Evaluate the follow questions: At what scale do fractures become important for degrading sealing capacity? What are the scaling relationships of fractures for seal litholgies at depths suited for CO_2 sequestration?
- Develop simple mechanical models to examine the linkages between rock properties and capillary-entry pressure and other matrix-scale-sealing behaviors that affect seal bypass

Relationship to program goals

- *Relationship to program goals* – We examine the mechanical stratigraphy of a natural analog for CO_2 sequestration caprock, and determine the geologic factors that influence its variability. We have also developed methods to correlate wireline log derived properties with field based observations. Caprock integrity is a key element in successful CO_2 storage
- *Success criteria* – benchmark against specific tasks and project elements; completing of student degrees; presentations at professional meetings; publications of papers

Seal bypass – means of fluid or gas escape from reservoirs



O_2 migration in the vadose zone can be modelled,
tations in the characterization of actual complex
nd CO_2 leakage scenarios.
sites that are offshore, CO_2 that has leaked may
n bottom sediments and then, if lighter than the
ater, migrate up through the water column until
atmosphere. Depending upon the leakage rate, it
main as a separate phase or completely dissolve

following pathways (Wo and Liang 2005; Wo *et a*
into surrounding strata during injection when high
used to inject CO_2 into low-permeability coal, eit
cleat system reaches the top of the seam or via h
induced to improve the contact between the clea
CBM production wells; through faults or other nat
intersecting the coal seam; via poorly abandoned
exploration wells; and through anthropomorphic p

Potential leakage pathways proposed by IPCC, 2005. Other mechanisms include Reservoir pressurization above the fracture strength of cap rock. In any engineered System, we want to avoid these. N. B. – careful site selection is crtical – many Faults, fracture zones, or old boreholes may be unrecognized

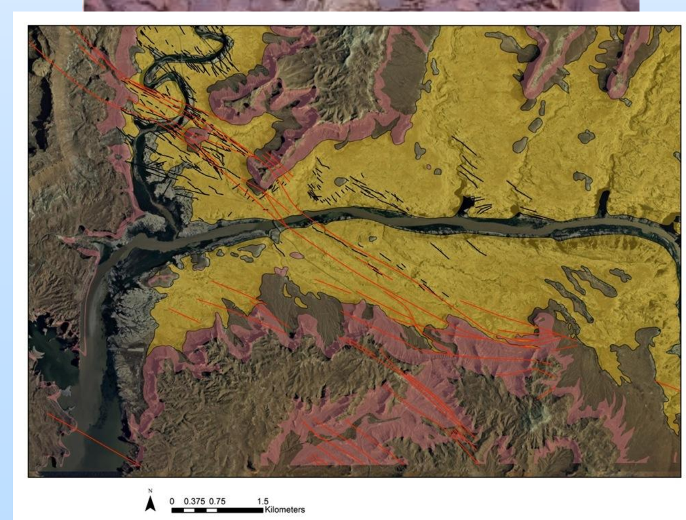
Examples of seal bypass

Drilling into CO_2 charged aquifer, July, 2012. CO_2 exsolves from groundwater 300 m BGL and produced geysers

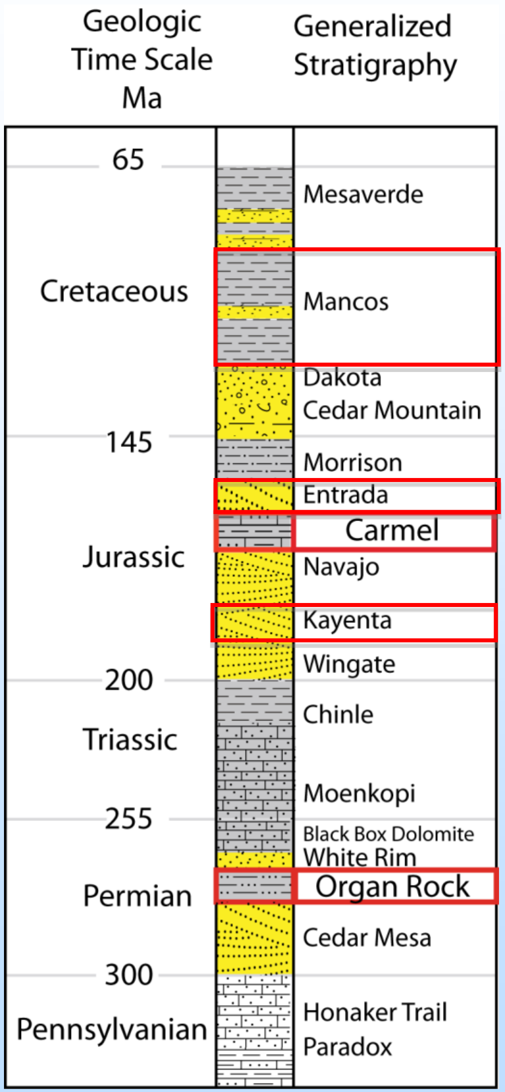
Travertine and tufa Developed along Little Grand Wash & Salt Wash faults, Utah, document > 100,000 years of leakage.

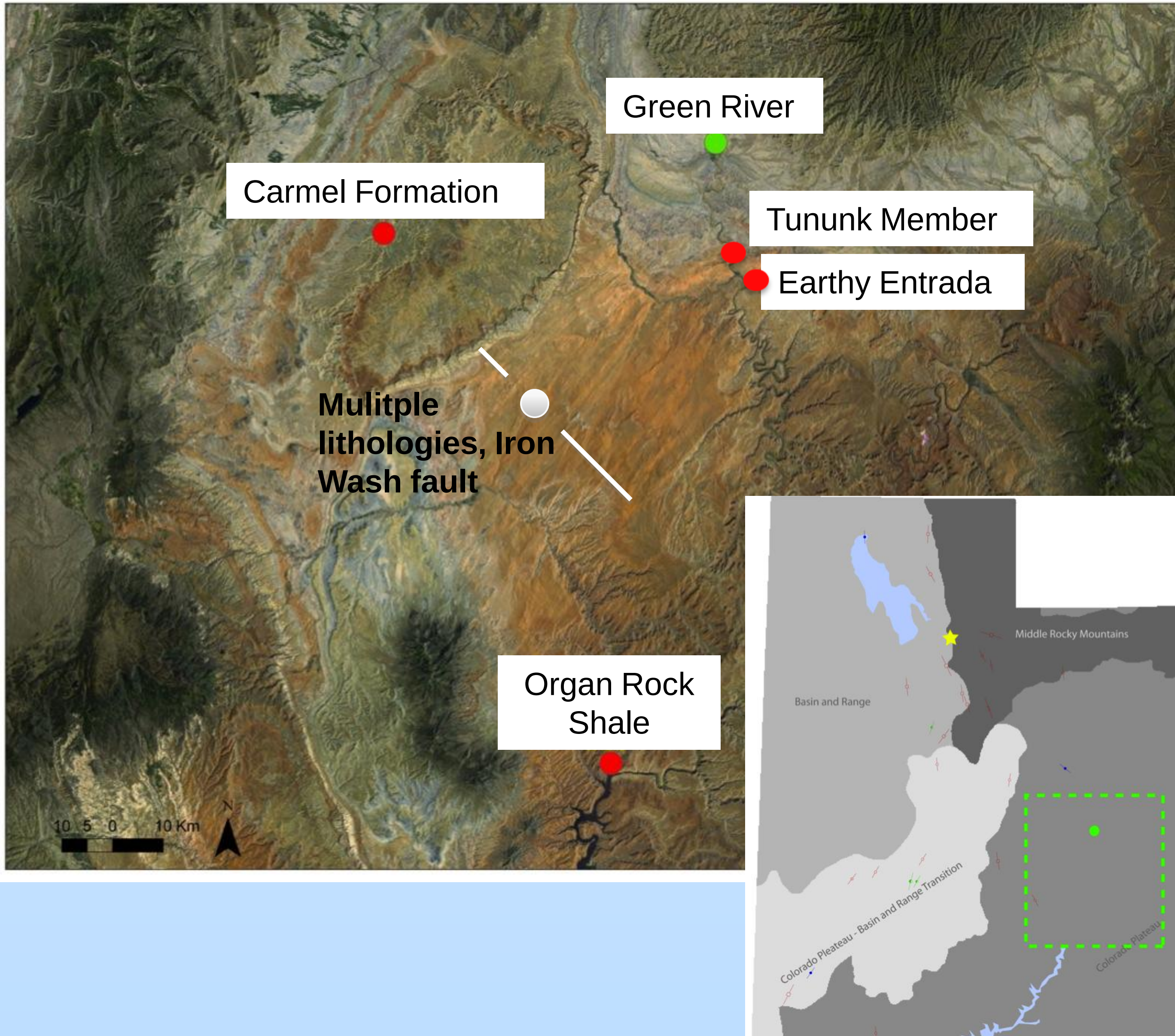
Technical status USU team examines MULTIPLE spatial scales of BYPASS – flow initiates at the interface; failure evolves to larger transport distances

- Sedimentary interfaces [with NMT, SNL; Mozley talk] – cm to m
- M to 10’s M scales [this study]
- 10’s M to km scale [this study]



Comparison of structural failure in four seal lithologies





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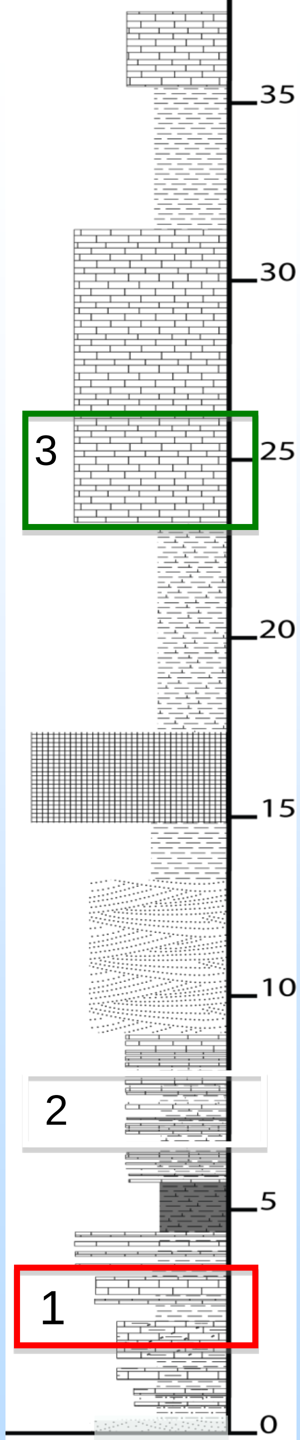
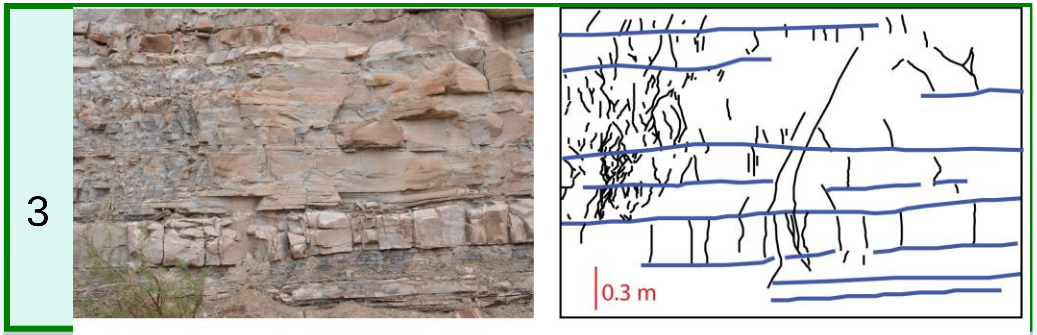
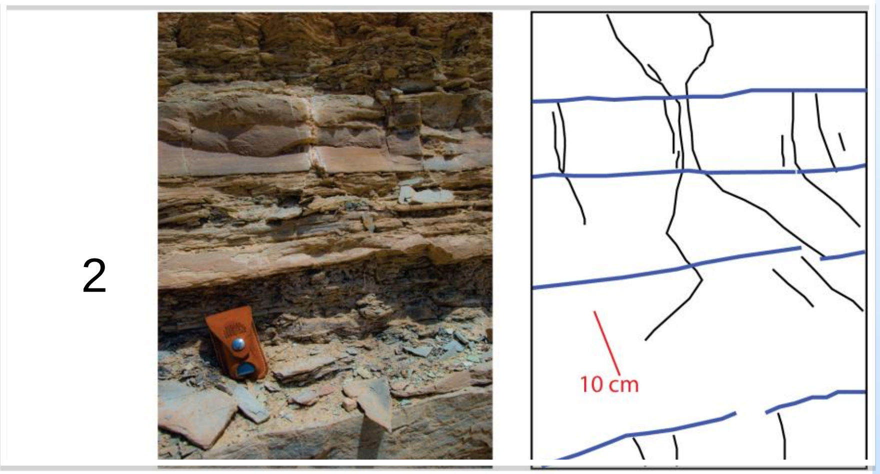
Outcrop analysis at the interface

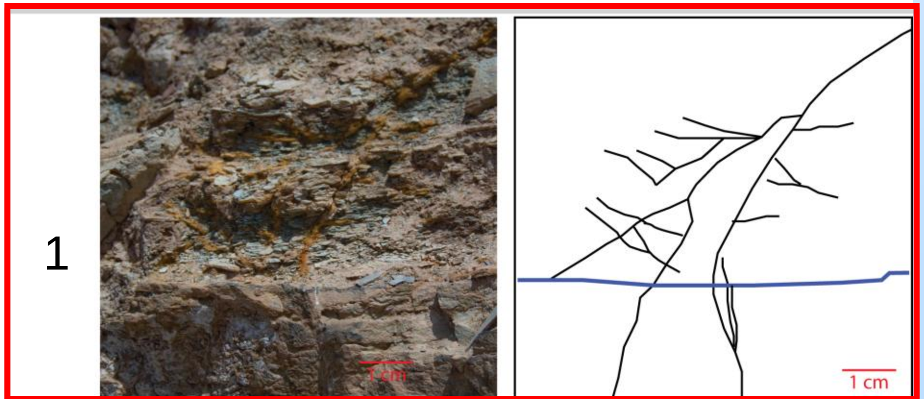




Fracture swarms associated with units lacking shale inter-beds and normal faults & spaced fractures



Splitting of fractures across lithologic boundaries



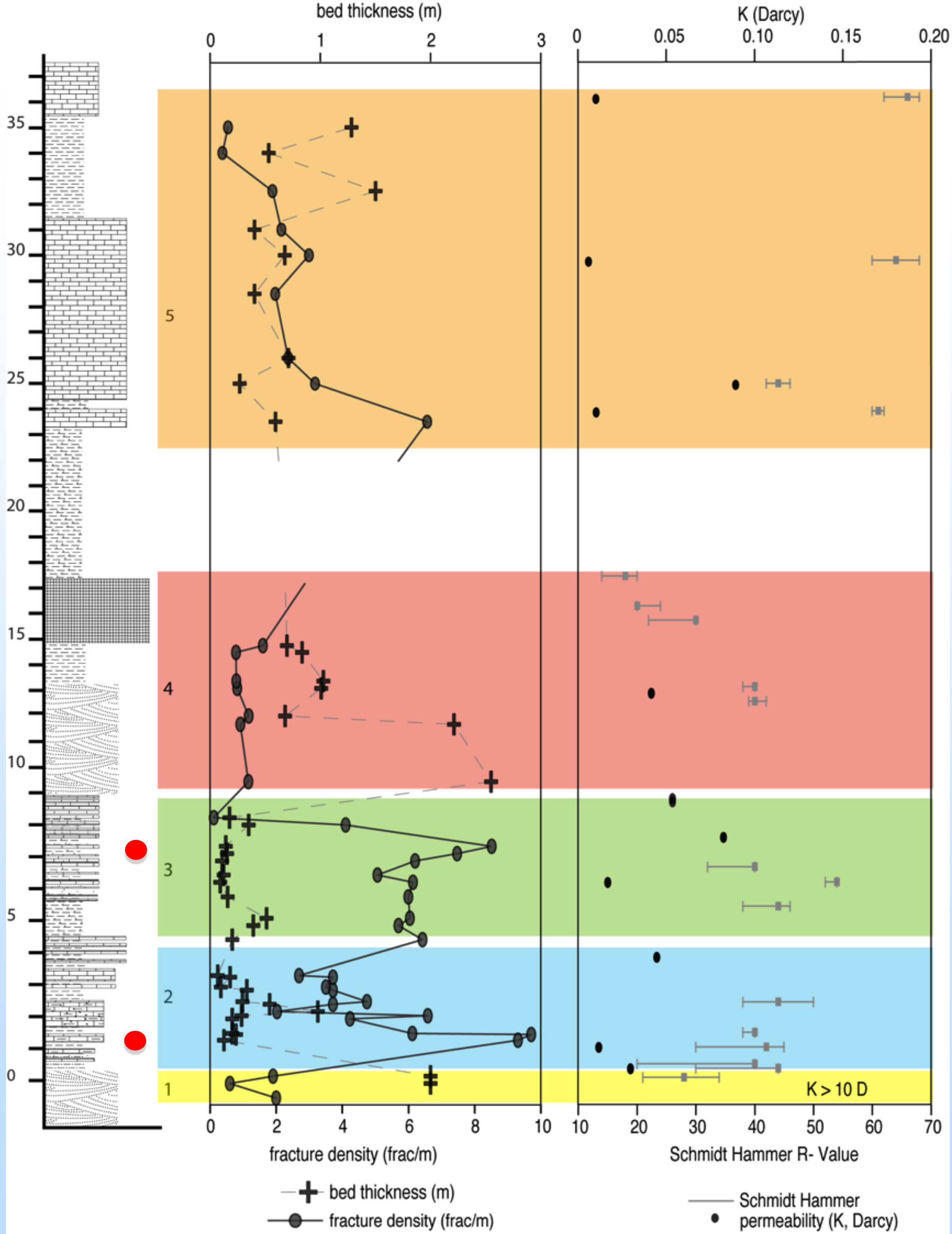
Deflection or arrest of mineralized fractures at interface

Mechanical stratigraphy

Determined from outcrop fracture density, Schmidt hammer, TinyPerm II, and bed thickness

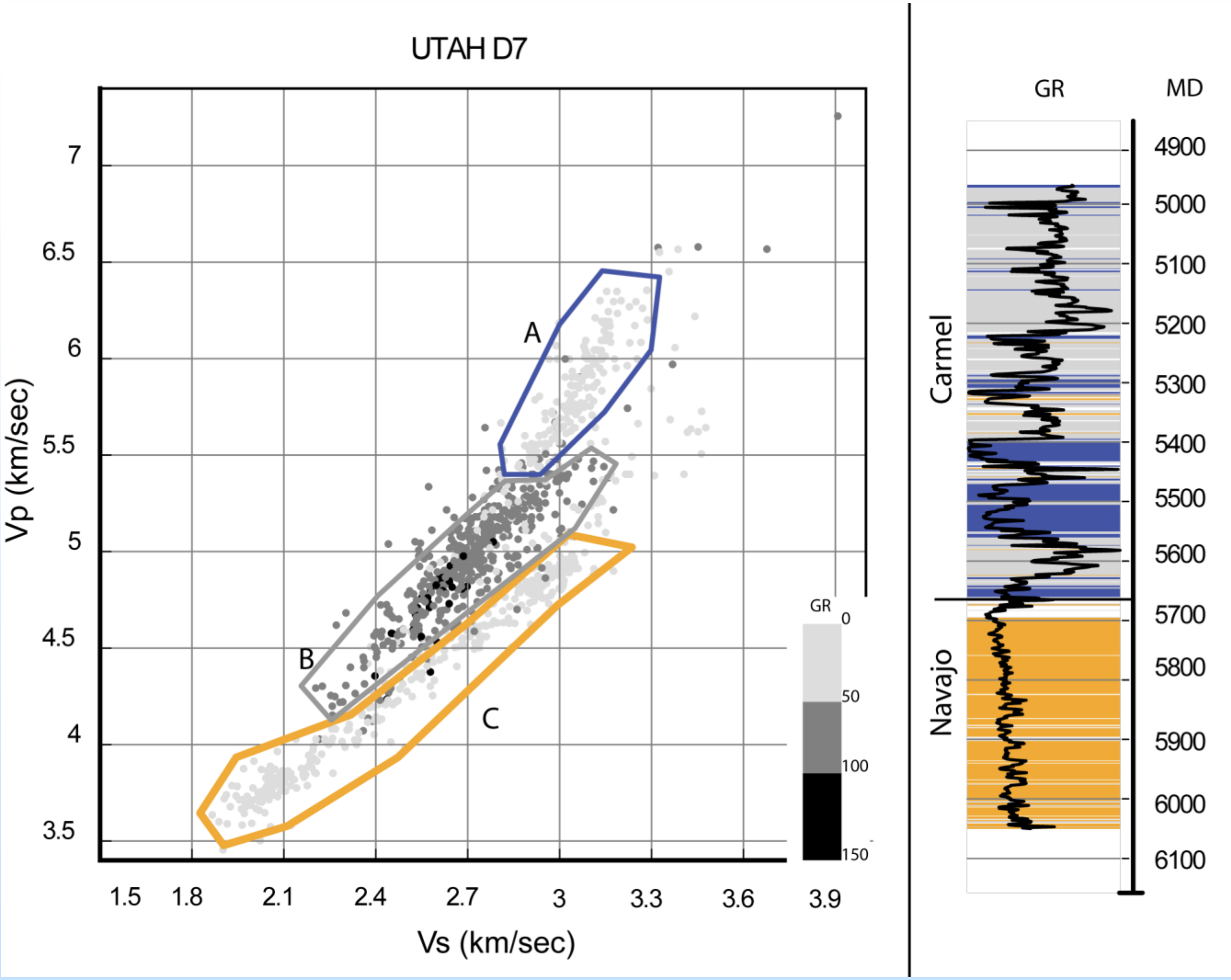
- **Bed thickness 0.25 – 3 m**
- **Higher fracture density in thin beds**
- **Compressive strength range 15-65**
- **Permeability range**

  > 0.01 D to 0.1 D



From Petrie et al., in press

Elastic moduli from wire line logs

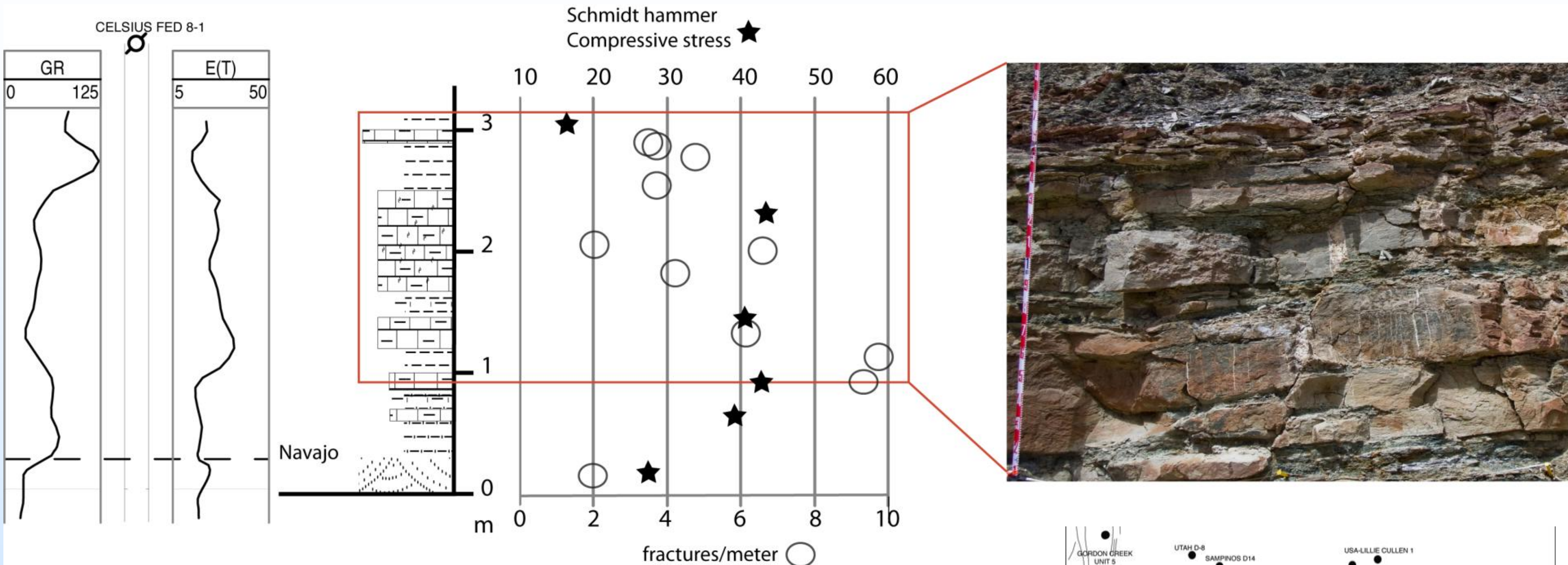


Gamma Ray	V_p/V_s	Cross plot
GR<50, Carmel	1.9	A
150>GR>50	1.8	B
GR<50, Navajo	1.6	C
GR>150	1.5	

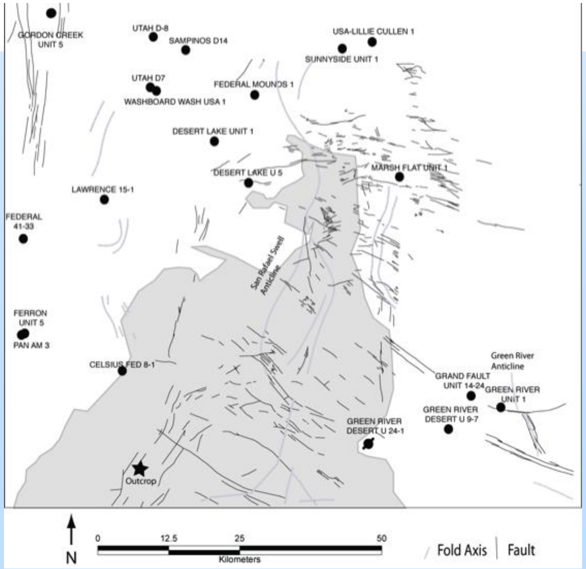
From: Petrie et al. in press 2012

Understanding caprock strength can be expanded from the outcrop, and quantified based on wireline log response. Wireline log data of either P-wave, or more modern data of dipole sonic data, from which we can determine elastic moduli, which we will use to model fracture development. Petrie determines three general groups of moduli using a cross plot method of Gamma Ray, and either dipole or P-wave data. For details, see Petrie et al., in press

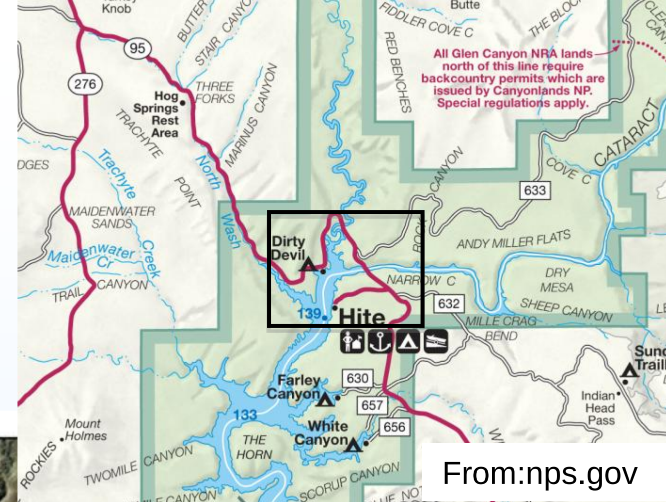
Subsurface to outcrop correlation



- Well-bore based estimates of dynamic Young's Modulus show meter scale variability (15-34 Gpa)
- Field-based fracture density and compressive strength also show meter scale variability
- How important is this variability to seal failure and subsurface fluid flow?

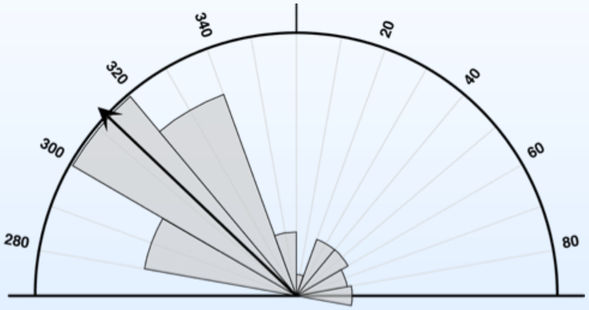


10's m – km scale - Cedar Mesa Discontinuities



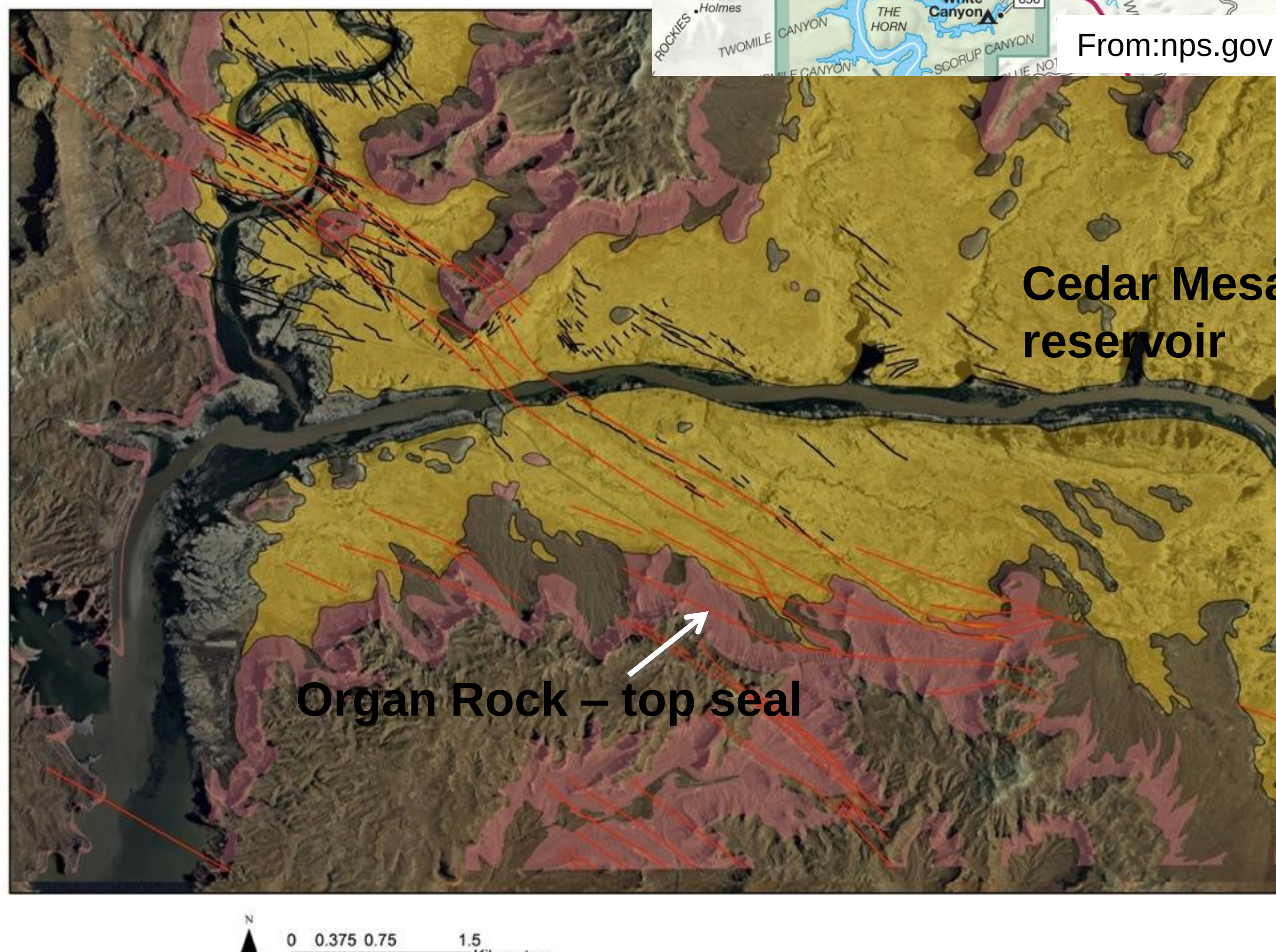
From:nps.gov

Examine sandstone – mudstone transitions in map and vertical sections, Lake Poweell



N: 342
Mean direction: 319°
Interval: 10°

- Cedar Mesa Sst
- Organ Rock Shale
- Normal faults
- Cedar Mesa joints



Modified from: Willis et al, UGS; Glen Canyon NRA

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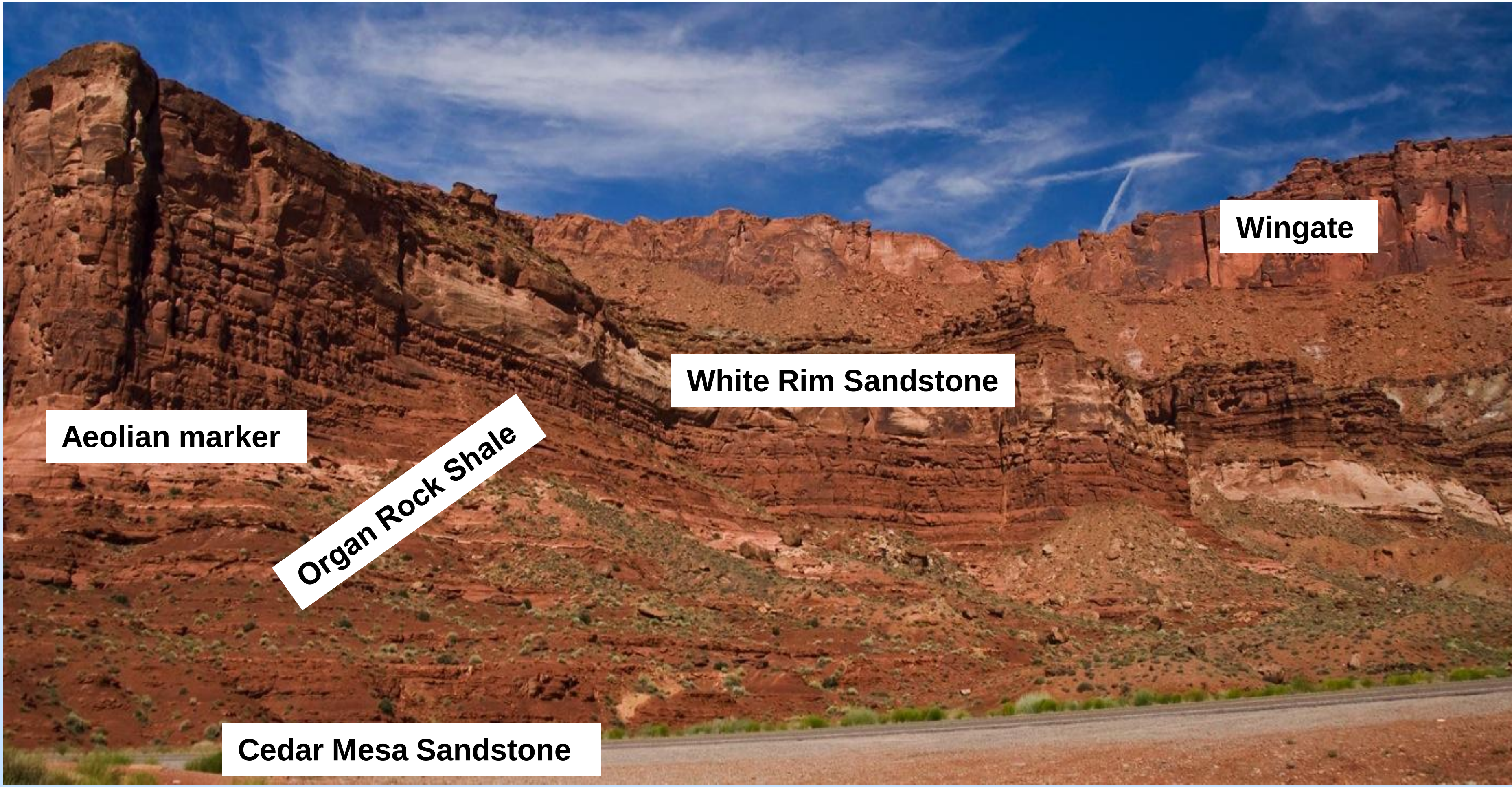
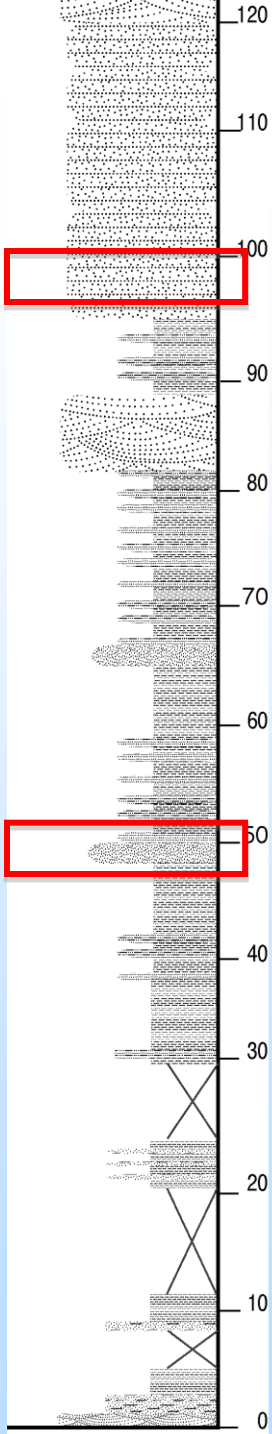
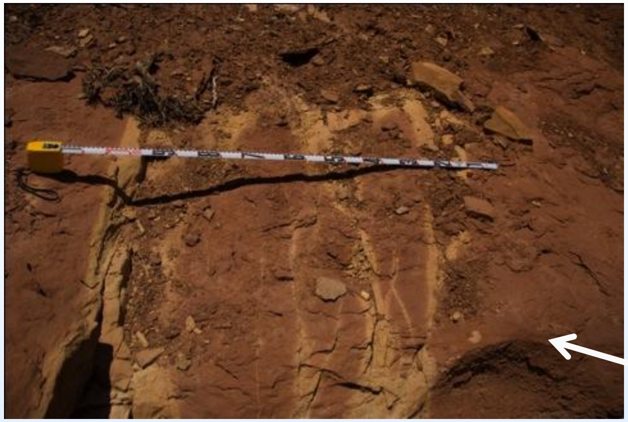
10-s 100s m – caprock Organ Rock Shale



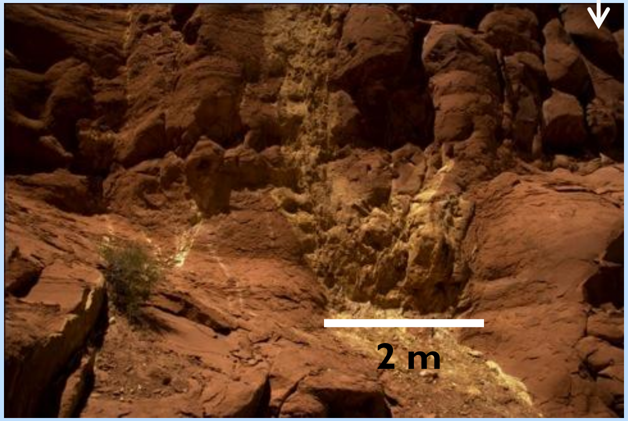
- Seal to the underlying Cedar Mesa Sandstone
- Coarsening up-ward interbedded siltstones & mudstones
- Deposited in near shore marine lowlands, braided streams & tidal flats



Organ Rock Shale Fracture Character & Distribution observed at multiple scales

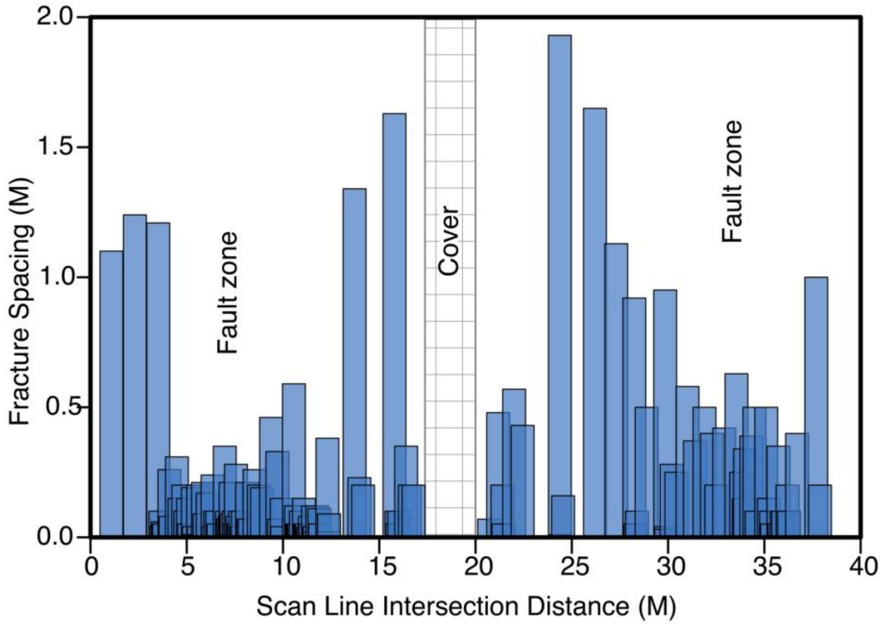


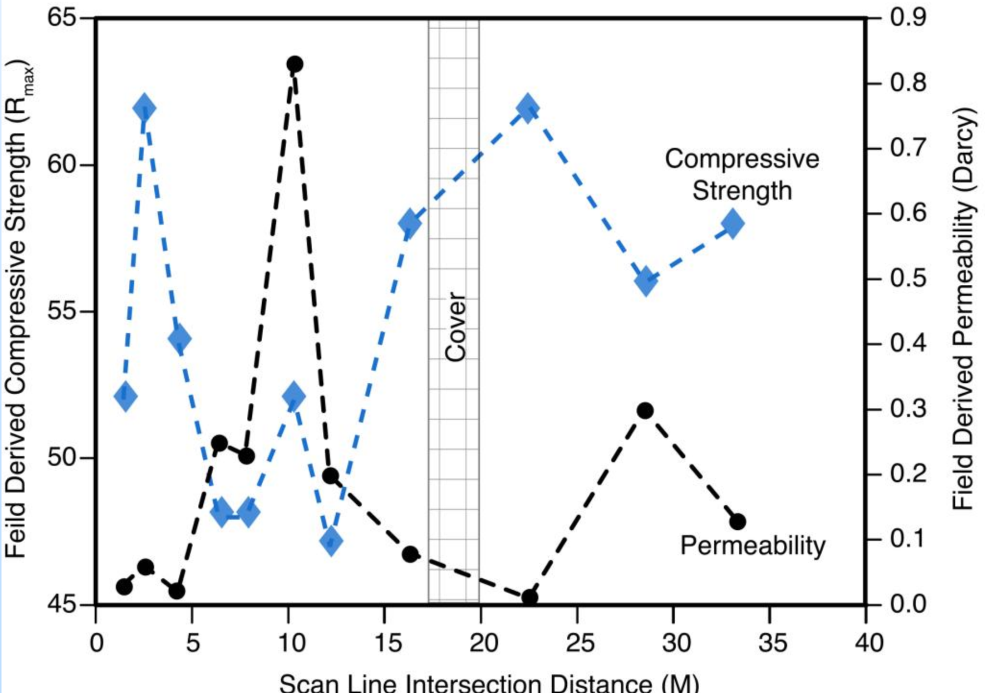
- Fracture trend parallels fault and joint trends
- Alteration halos and mineralization suggests fluid flow along fractures
- Fracture density increases with proximity to faults and in coarse-grained lithology
- Mean fracture spacing 1 fracture/0.2 meters



M – 10’s m Cedar Mesa Sandstone

Scan line location ~ 2-15m on graphs



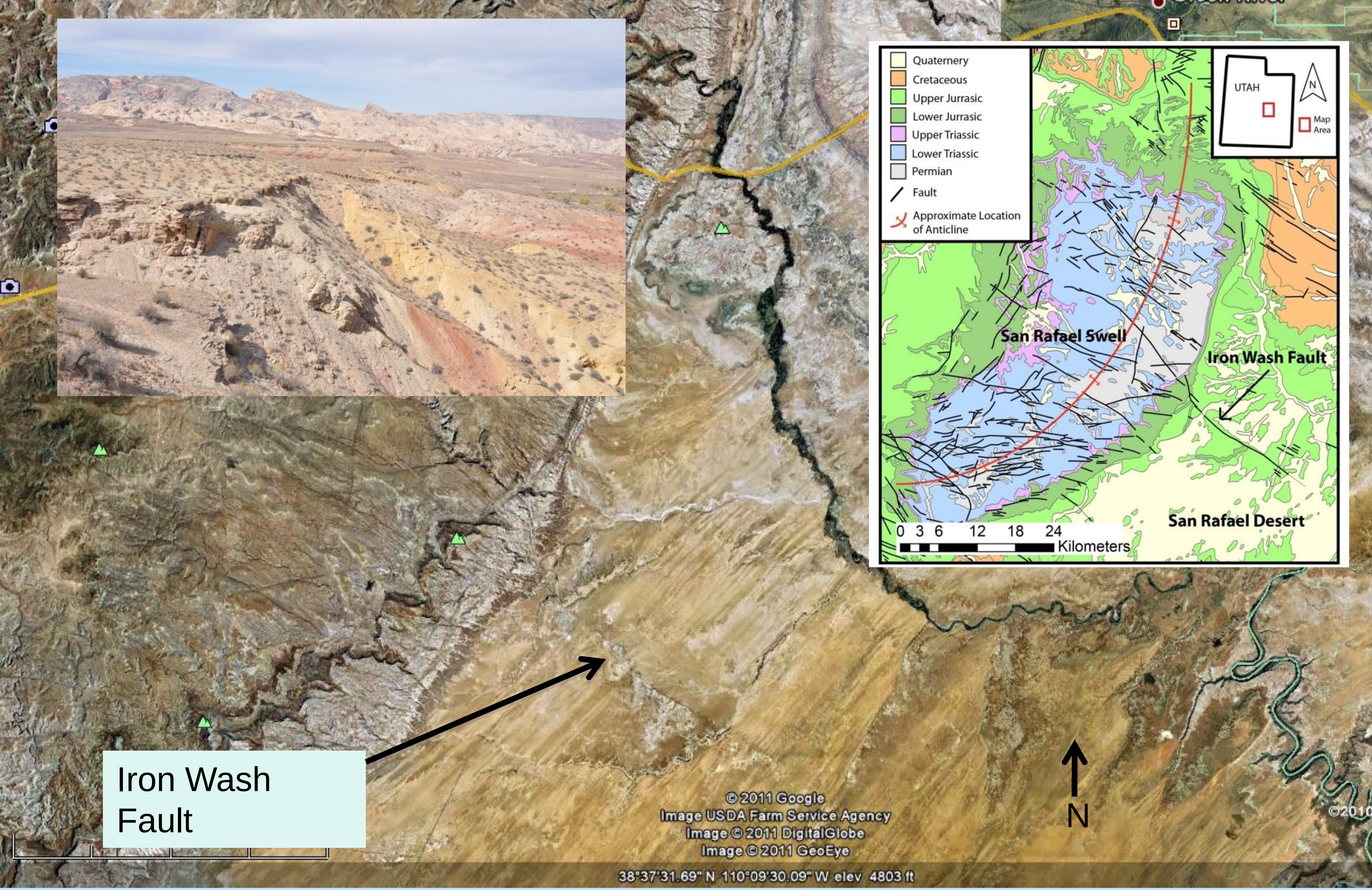


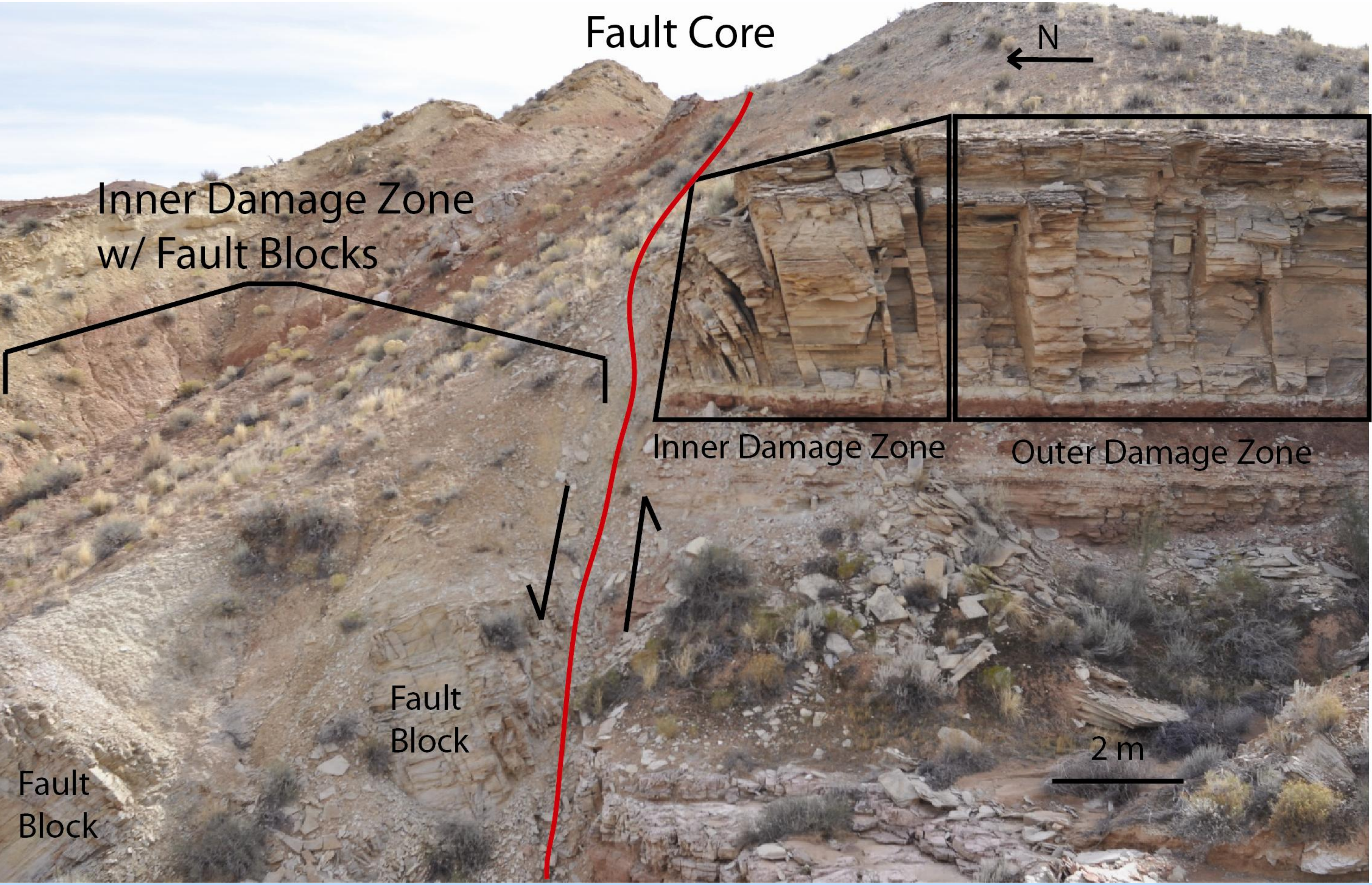
Fault zones exhibit:

- Increase in fracture density, typically mineralized
- Decease in compressive rock strength
- Increase in sandstone rock permeability creates fluid pathways in reservoir

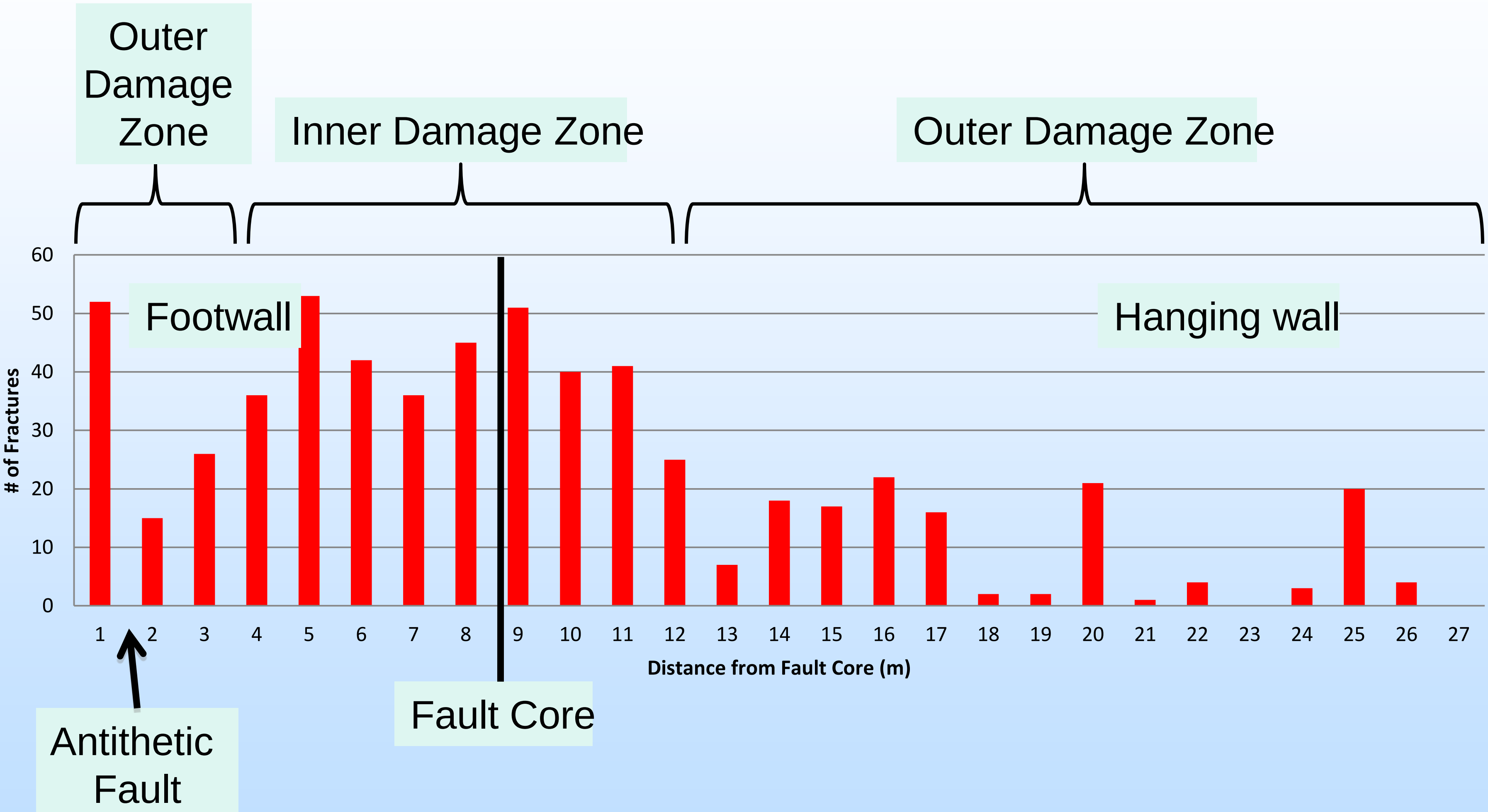
1- 10 km scale

ARCHITECTURE AND SPATIAL VARIATIONS OF FAULT ZONE STRUCTURE; IMPLICATIONS FOR FAULT PERMEABILITY AND FLUID MIGRATION PATHWAYS –



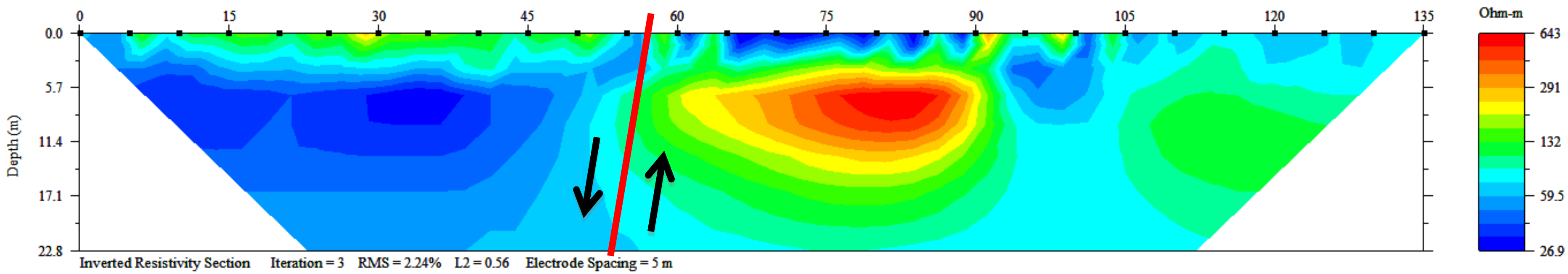


Fault Core
N
Inner Damage Zone
w/ Fault Blocks
Inner Damage Zone
Outer Damage Zone
Fault
Block
Fault
Block
2 m

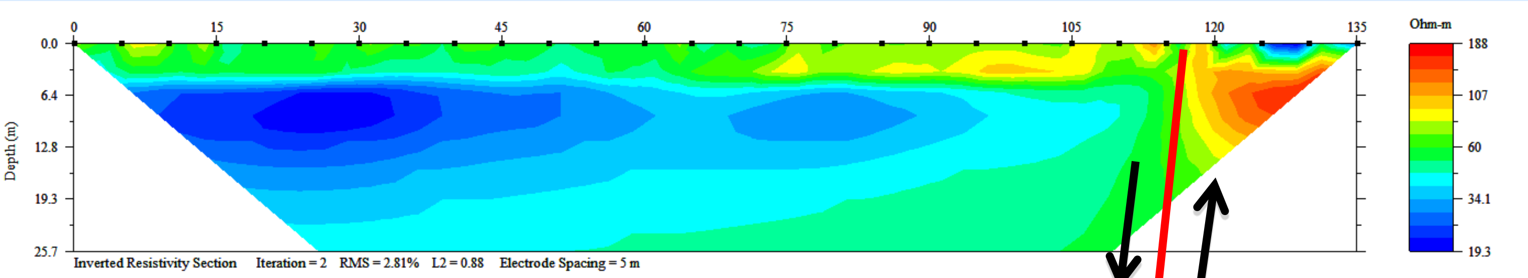


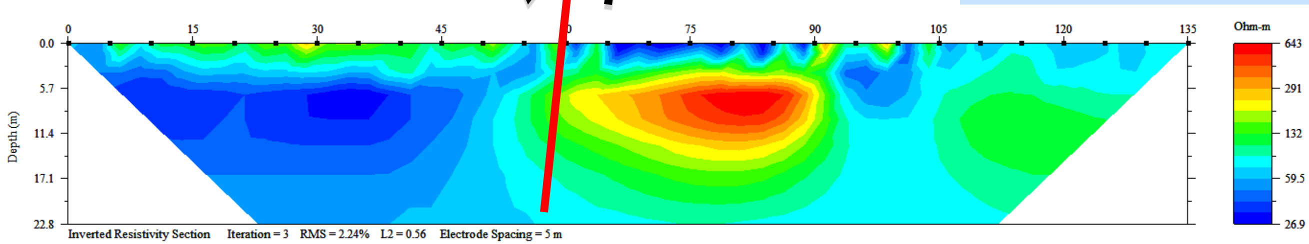
Outer Damage Zone
Inner Damage Zone
Outer Damage Zone
60
50
40
30
20
10
0
# of Fractures
Footwall
Hanging wall
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Distance from Fault Core (m)
Antithetic Fault
Fault Core

Major outcome of all these studies Applications of Technology to characterize These rocks

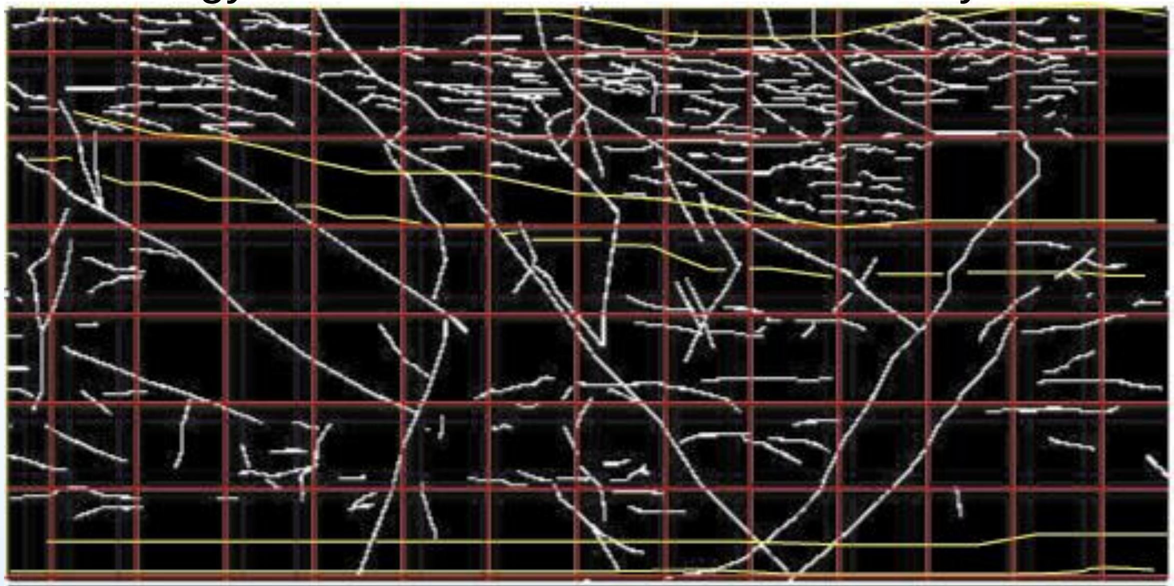


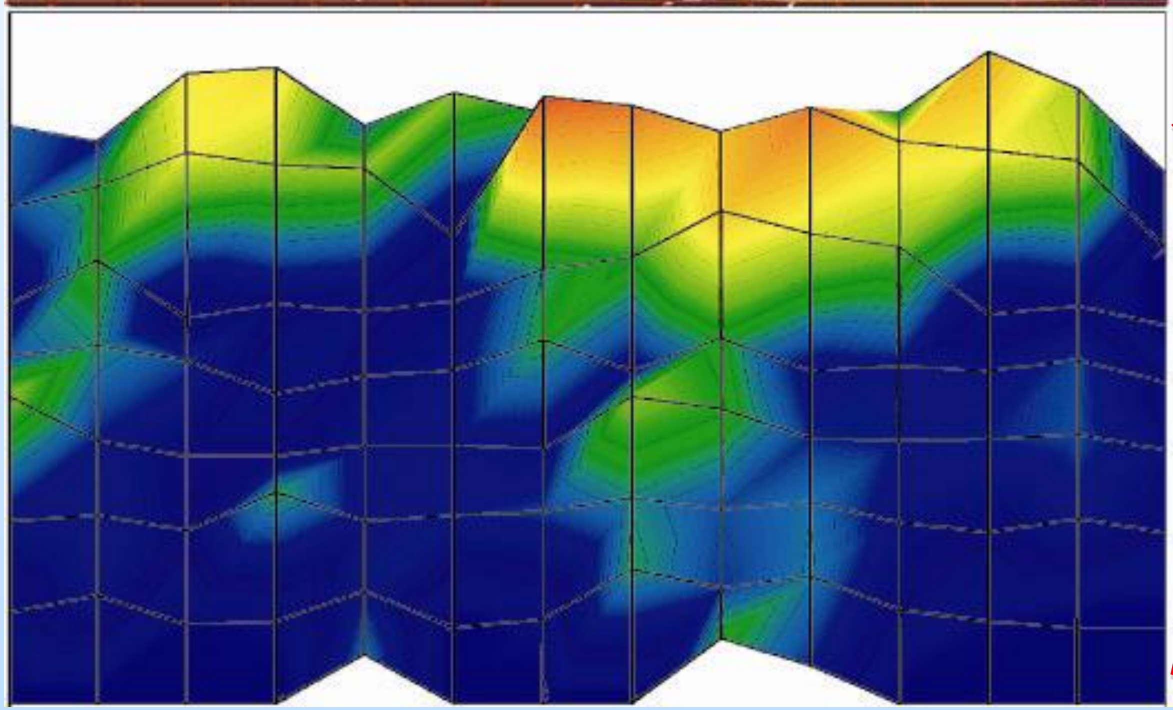
a. DC Electrical Resistivity Survey
b. Reflection seismic work – fall 2012

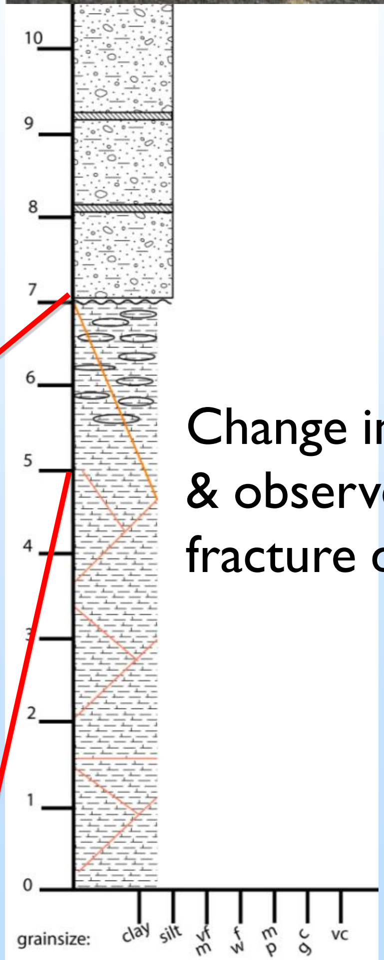




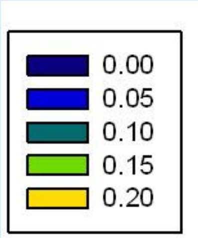
Technology – use of Sirovision and data analyes





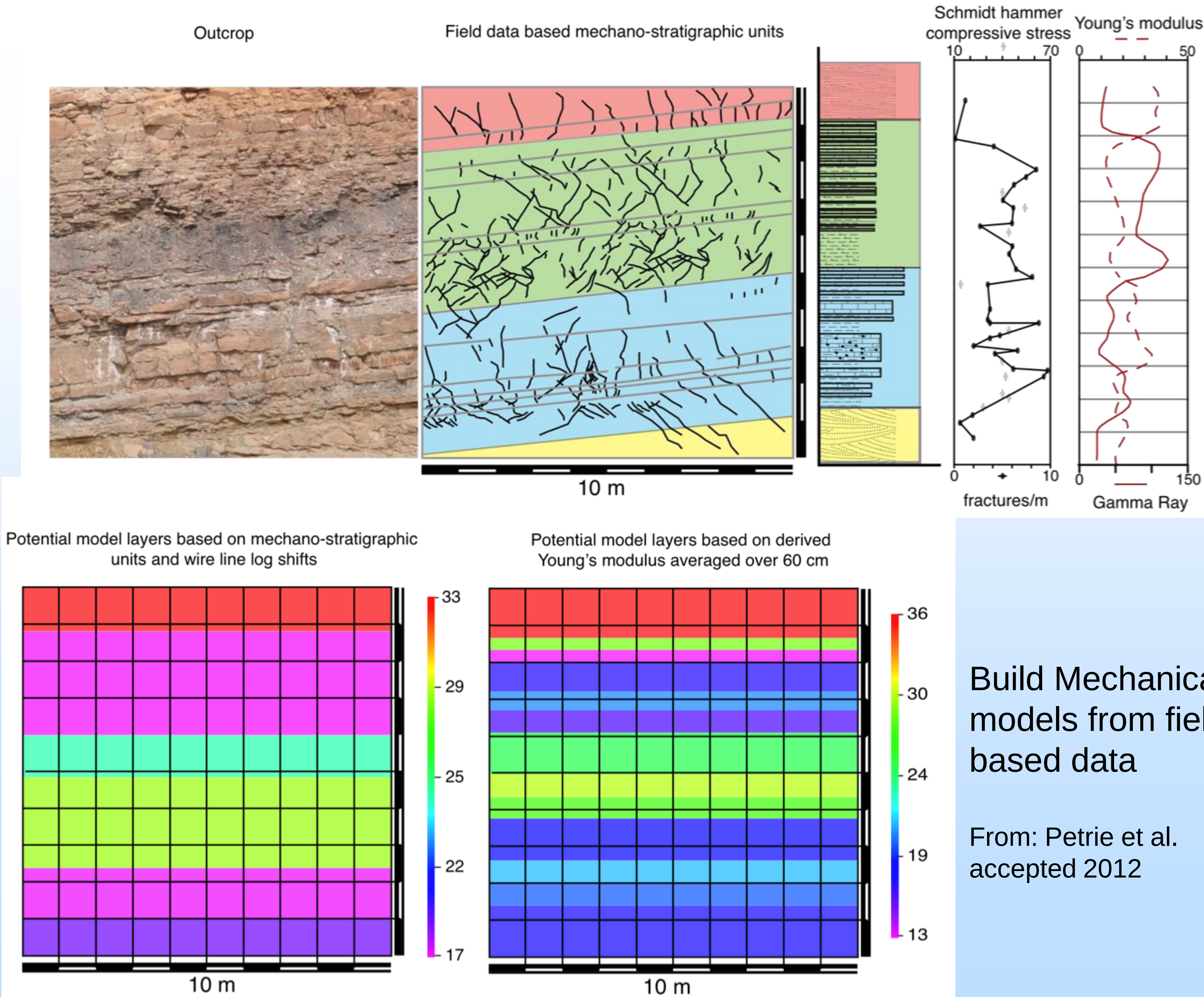


Change in lithology & observed increase fracture density



Surface plot of fracture density

Fracture density calculated as the area (decimal) of fractures per each 20cm^2 grid cell

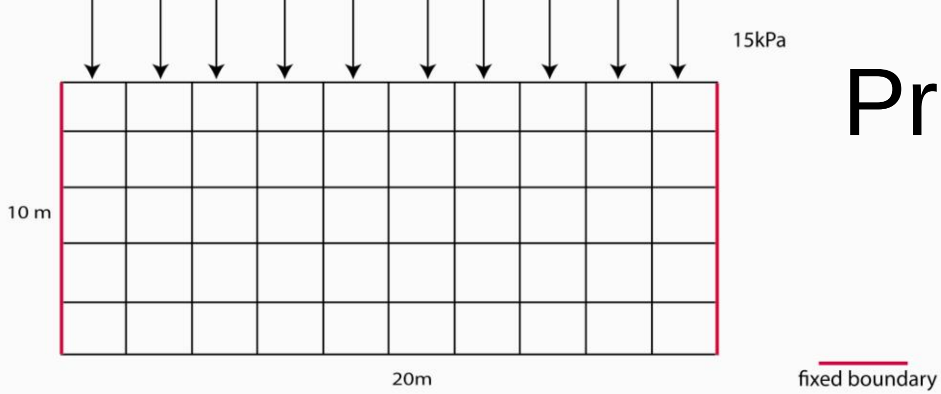


Build Mechanical models from field based data

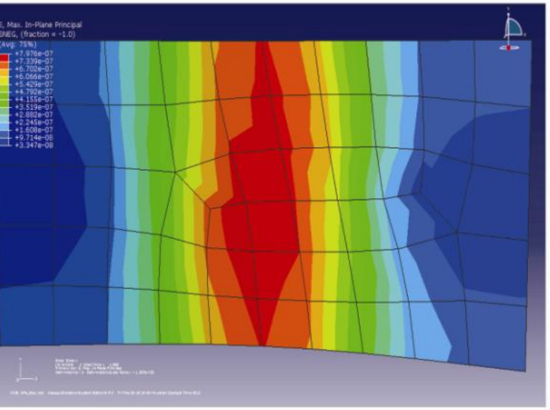
From: Petrie et al. accepted 2012

Preliminary Modeling

10x20 m block
15 MPa load

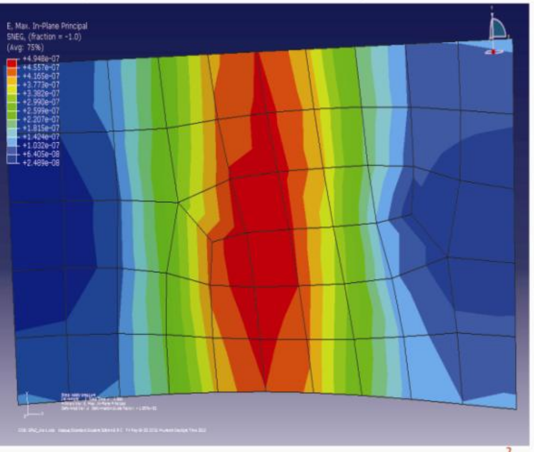


E, Max In-Plane Principal



Young's Modulus: 18.32
Poisson's Ratio: 0.27
E range: $3.4e^{-8}$ to $7.8e^{-7}$

E, Max In-Plane Principal



Young's Modulus: 29.34
Poisson's Ratio: 0.30
E range: $25e^{-8}$ to $49e^{-6}$

- Significant difference observed in the magnitude of the maximum in-plane principal stress
- Can use this to predict fracture distribution in caprock, using fluid pressures

Accomplishments to Date

- Characterized seal bypass in naturally formed four reservoir seal systems, at cm to km scales
- Developed a workflow to quantify mechanical and flow properties of rock, fractured rock, and fault zones
- Developed method to determine elastic moduli from field and wireline data
- Started mechanical modeling of stresses and fracture development in these systems
- Applied a range of techniques to these studies

Summary

- Key Findings
  - Cm to reservoir-scale fractures and faults crea flow paths into and across caprocks
  - Heterogeneity in strength due to sedimentological variations
  - Can capture and model properties
- Lessons Learned
  - Multiple scales, multiple techniques
- Future Plans
  - Mechanical modeling
  - Complete UV light surveys, paper
  - Complete Iron Wash study
  - Fault geophysics

Organization Chart

Peter Mozley
NMT
Sedimentology

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

James Evans (PI)
USU

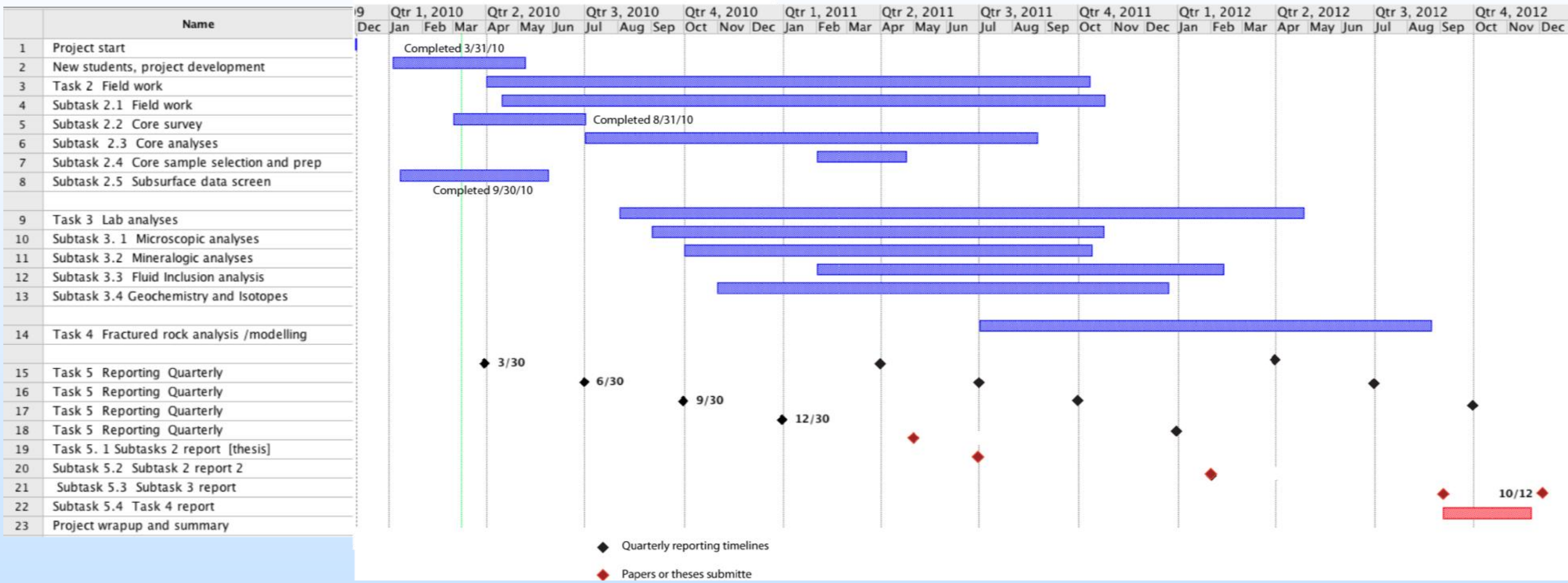
Elizabeth Petrie [PhD, 2013]
David Richey [MS, 2013]
Corey Barton [MS, 2011]
Elizabeth Horne [BS, 2013]
Tamara Jeppson [BS, 2010]
Nathan Giles [BS, 2012; MS 2014]

UtahState University

Thomas Dewers
(Co-I)
Jason Heath
(Staff)
SNL
Modeling

Sandia National Laboratories
Exceptional service in the national interest

Gantt Chart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Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1 Project start
2 New students, project development
3 Task 2 Field work
4 Subtask 2.1 Field work
5 Subtask 2.2 Core survey
6 Subtask 2.3 Core analyses
7 Subtask 2.4 Core sample selection and prep
8 Subtask 2.5 Subsurface data screen
9 Task 3 Lab analyses
10 Subtask 3. 1 Microscopic analyses
11 Subtask 3.2 Mineralogic analyses
12 Subtask 3.3 Fluid Inclusion analysis
13 Subtask 3.4 Geochemistry and Isotopes
14 Task 4 Fractured rock analysis /modelling
15 Task 5 Reporting Quarterly
16 Task 5 Reporting Quarterly
17 Task 5 Reporting Quarterly
18 Task 5 Reporting Quarterly
19 Task 5. 1 Subtasks 2 report [thesis]
20 Subtask 5.2 Subtask 2 report 2
21 Subtask 5.3 Subtask 3 report
22 Subtask 5.4 Task 4 report
23 Project wrapup and summary
Completed 3/31/10
Completed 8/31/10
Completed 9/30/10
3/30
6/30
9/30
12/30
10/12
Quarterly reporting timelines
Papers or theses submitte

Bibliography

Petrie, E. S., Jeppson, T M., and Evans, J. P., in press, Predicting rock strength variability at stratigraphic interfaces in caprock lithologies at depth: Correlation between outcrop and subsurface, in: Environmental Geosciences, Dec., 2012.

Pasala, S., Forster, C. B., Deo, M., and Evans, J. P., submitted, Simulation of the impacts of faults on CO2 injection into sandstone reservoirs, to: Environmental Geosciences.